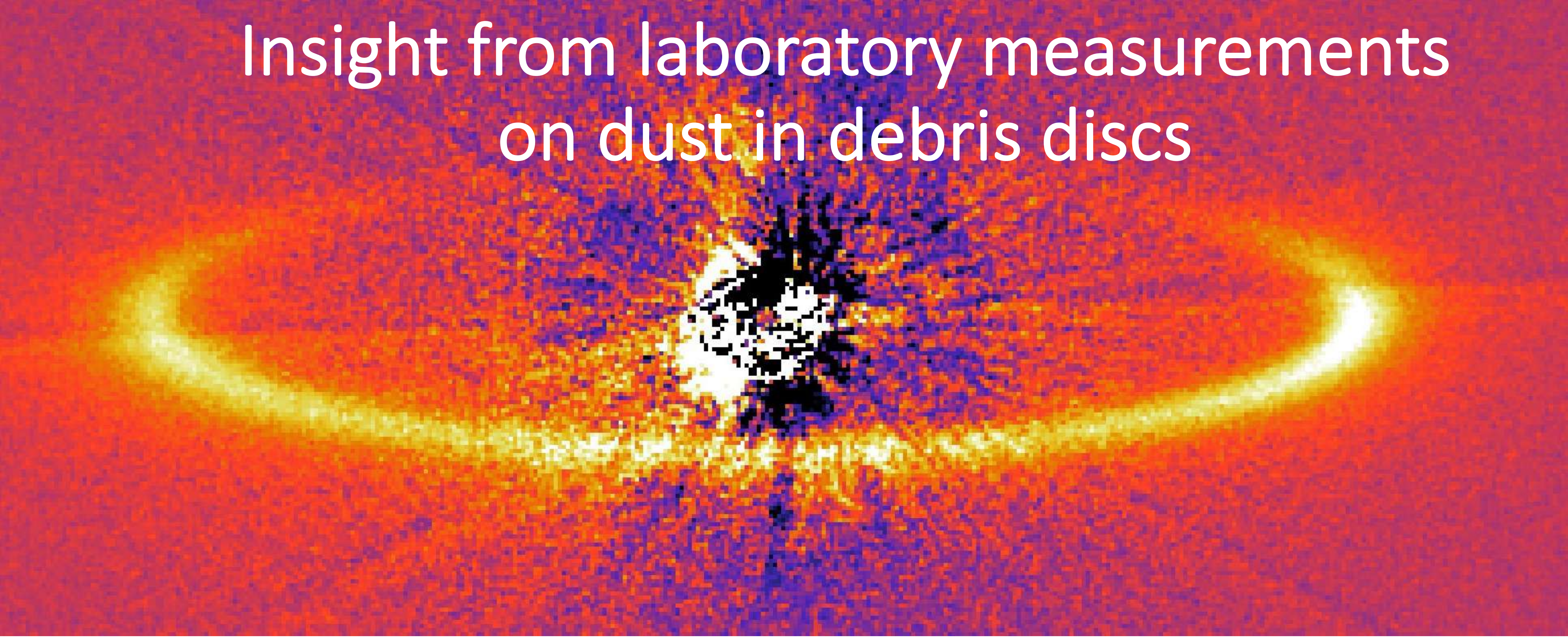
Insight from laboratory measurements on dust in debris discs



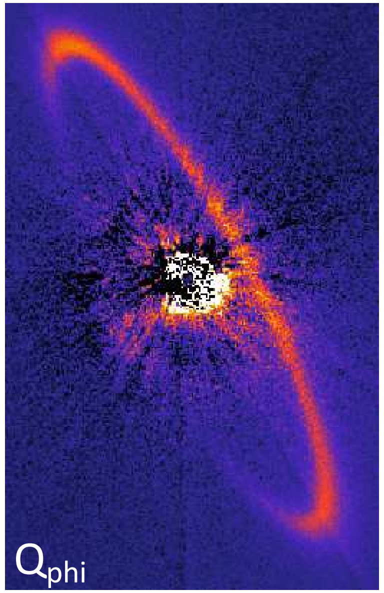
Julien Milli

with Olivier Poch, Jean-Charles Augereau, Clément Baruteau, Pierre Beck , Elodie Choquet, Jean-Michel Geffrin, Edith Hadamcik, Anny-Chantal Levasseur-Regourd, Jérémie Lasue, Francois Ménard, Arthur Peronne, Jean-Baptiste Renard, Vanesa Tobon-Valencia

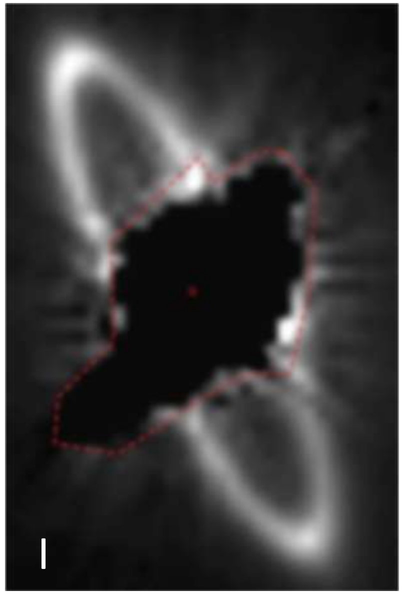
IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

Context: the HR4796 debris disk

Optical regime

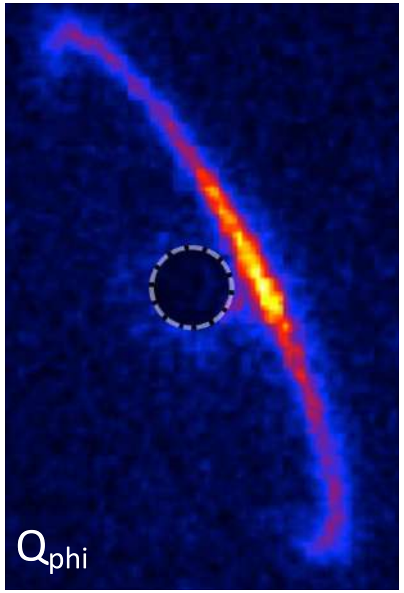


SPHERE 0.6-0.9 μm
(Milli et al. 2019,
Olofsson et al. 2020)

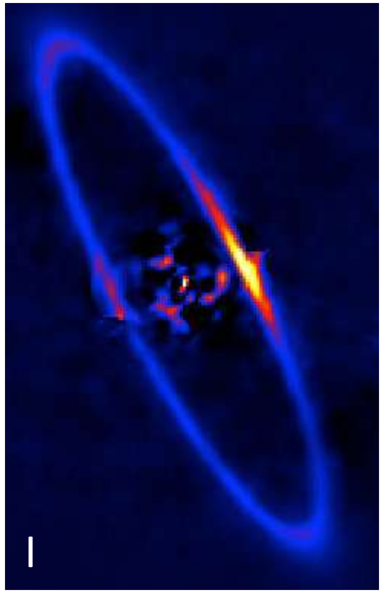


STIS 0.36-0.8 μm
(Schneider et al. 2017)

Near-infrared regime



GPI 2.2 μm
(Perrin et al. 2014,
Arriaga et al. 2020)



SPHERE 1.6 μm
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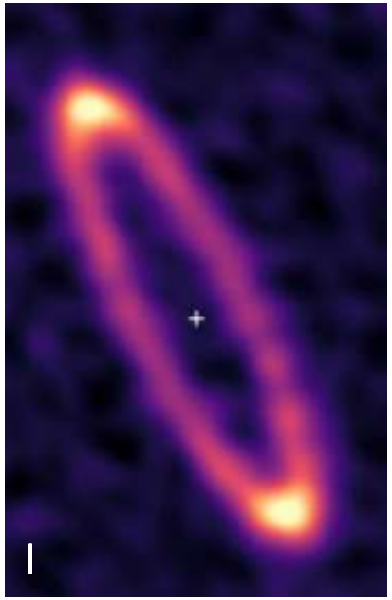
Thermal regime



ALMA 880 μm
(Kennedy et al. 2018)

A0V star at 70.8 pc and 10 Myrs (TW Hydra member)
Strong infrared excess of 0.5%

Context: the HR4796 debris disk

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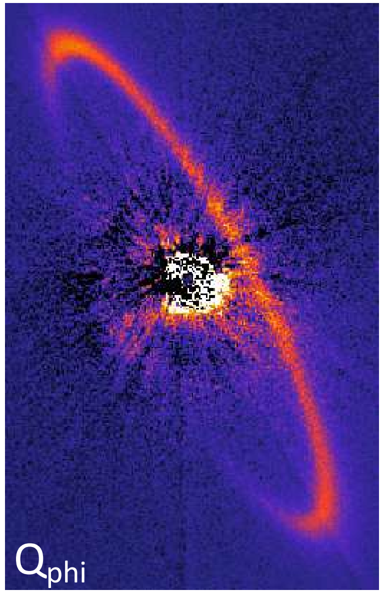

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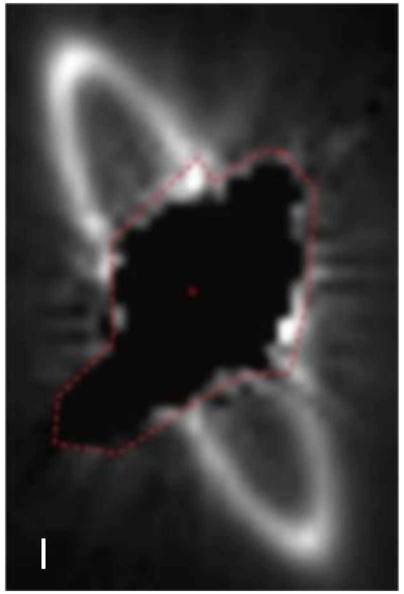

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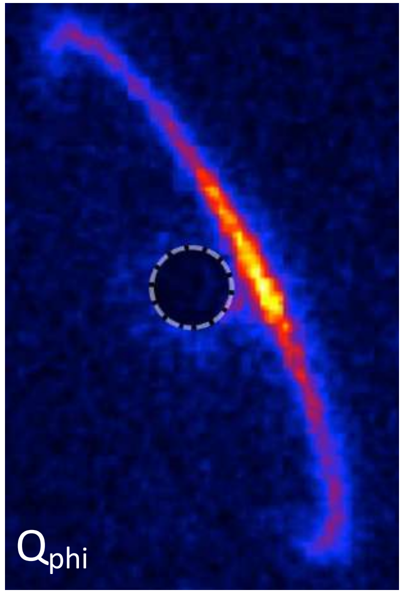

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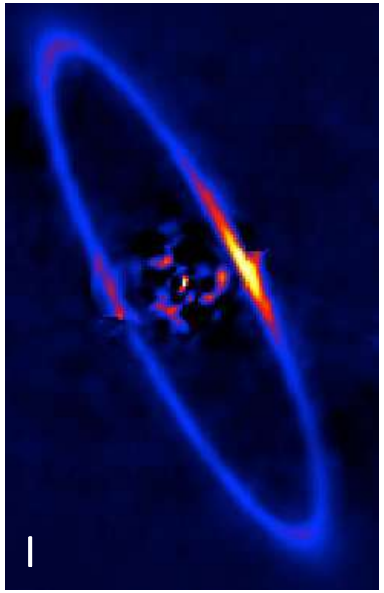

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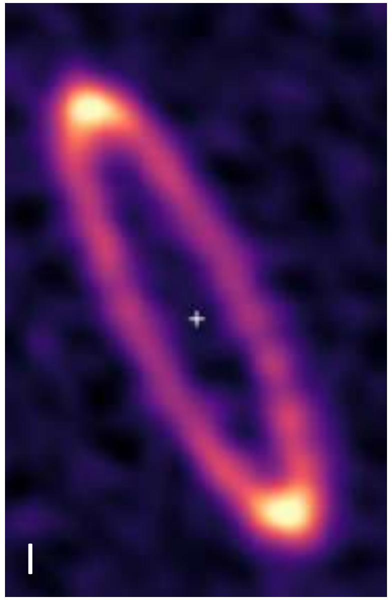

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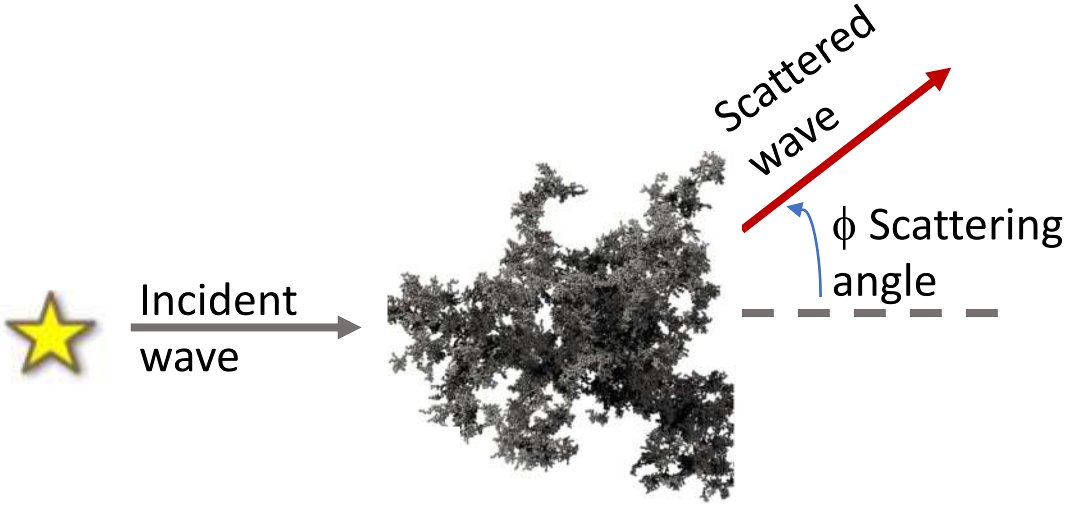
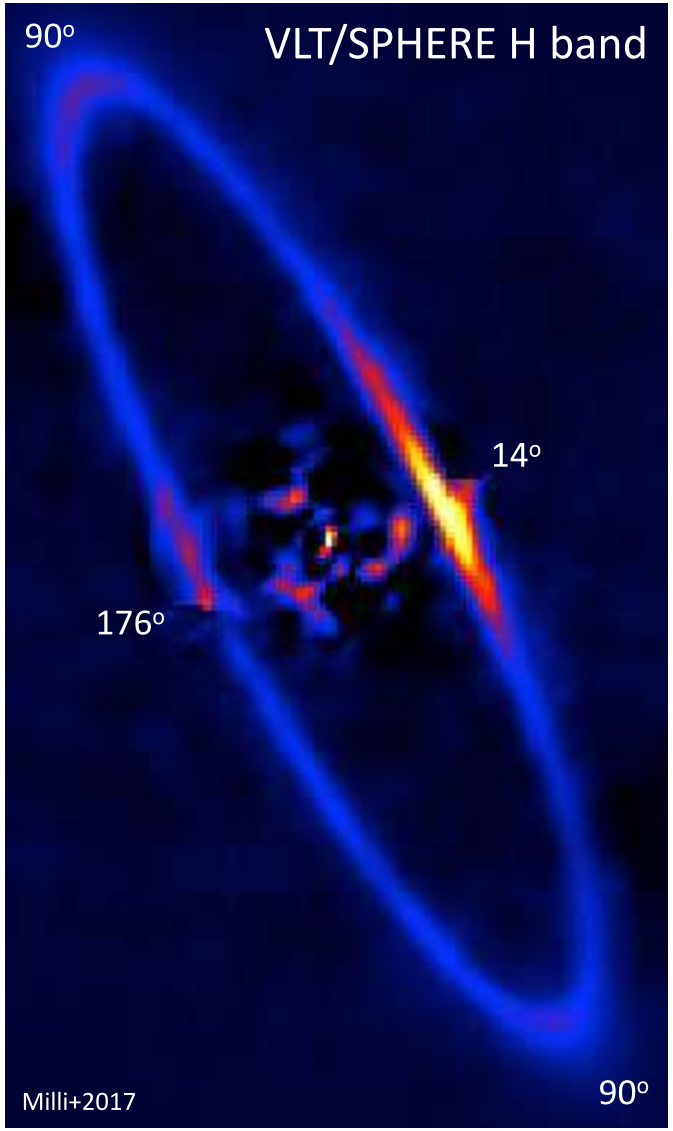
Strong infrared excess of 0.5%

Scattering properties as a remote sensing tool





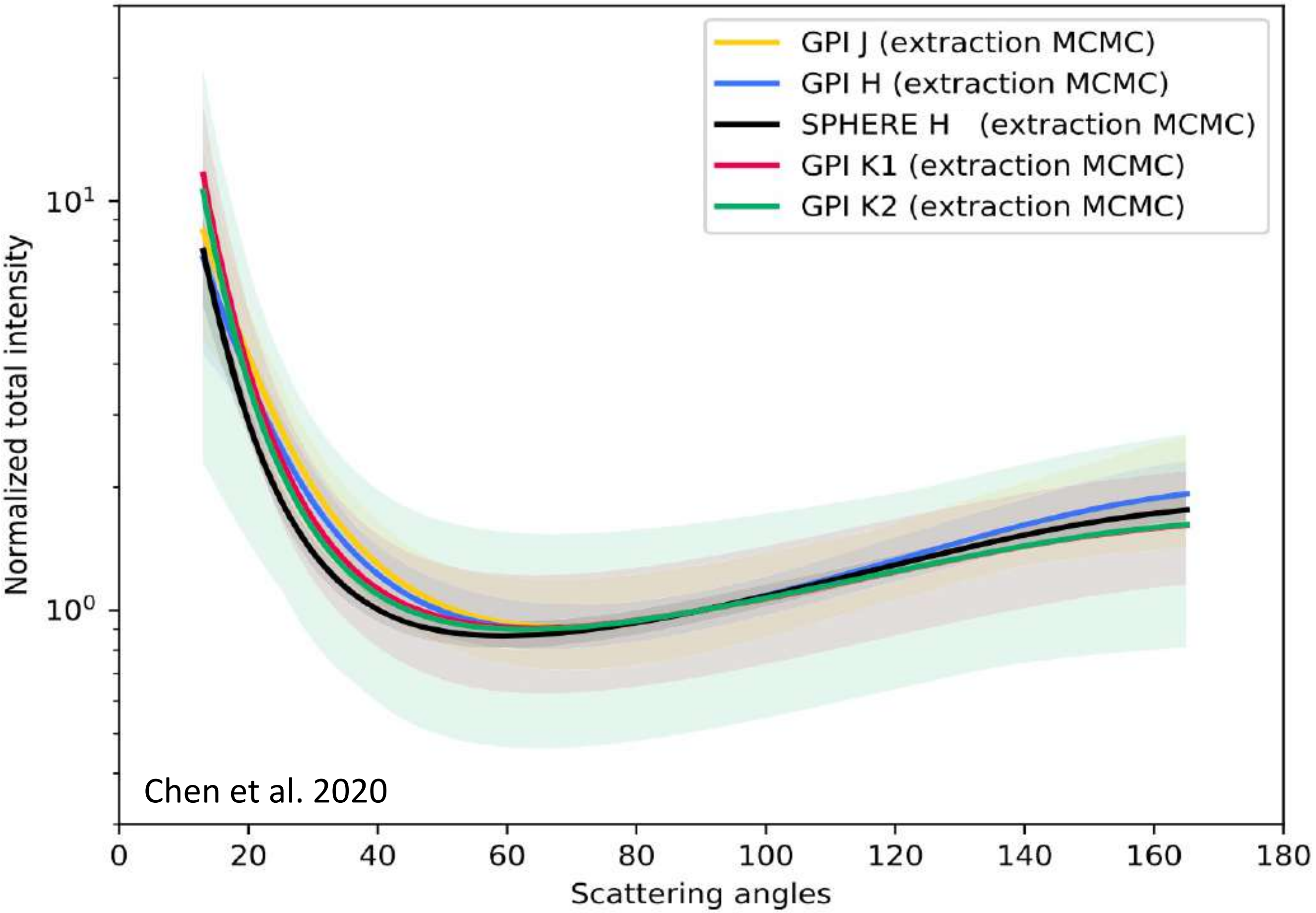
3 Observables:

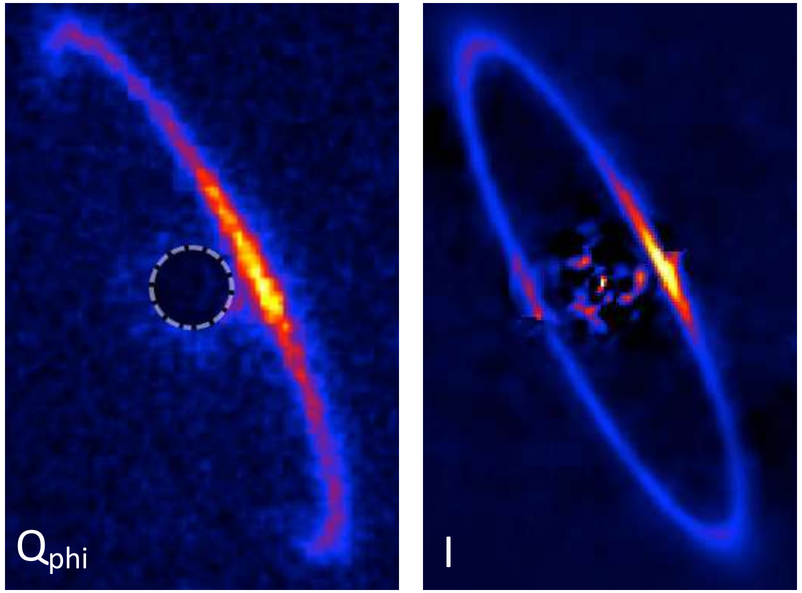
- Phase function
- Linear degree of polarisation
- As a function of wavelength (colour)

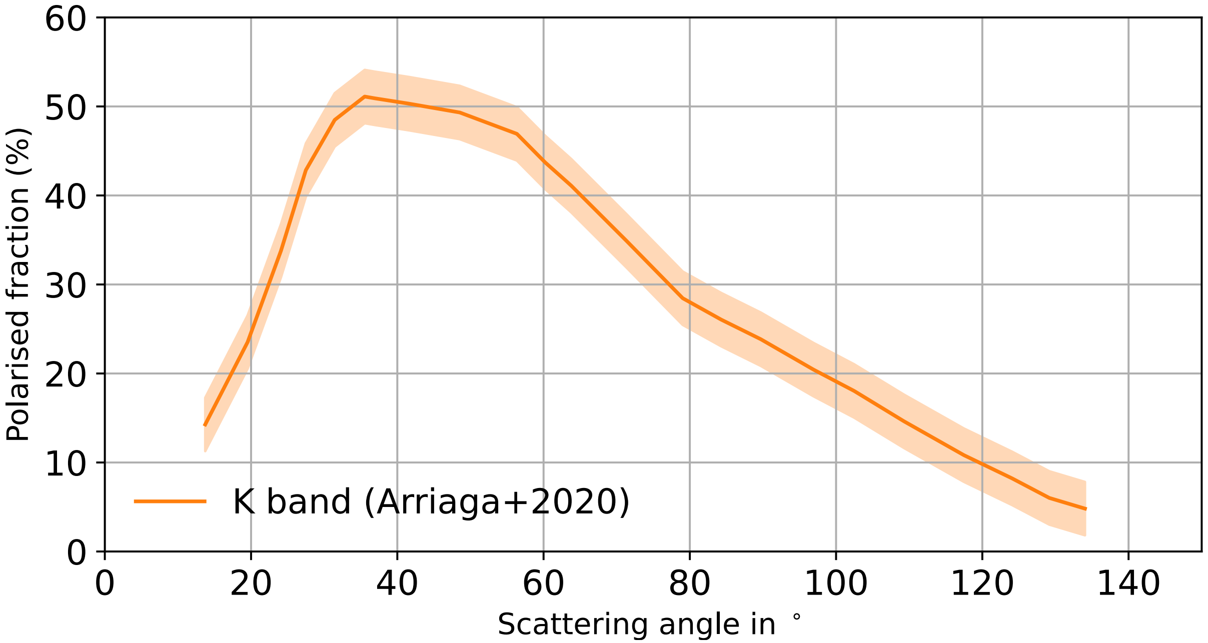
Interpretation

- Dust Size
- Shape
- Porosity
- Composition

Observations of HR4796

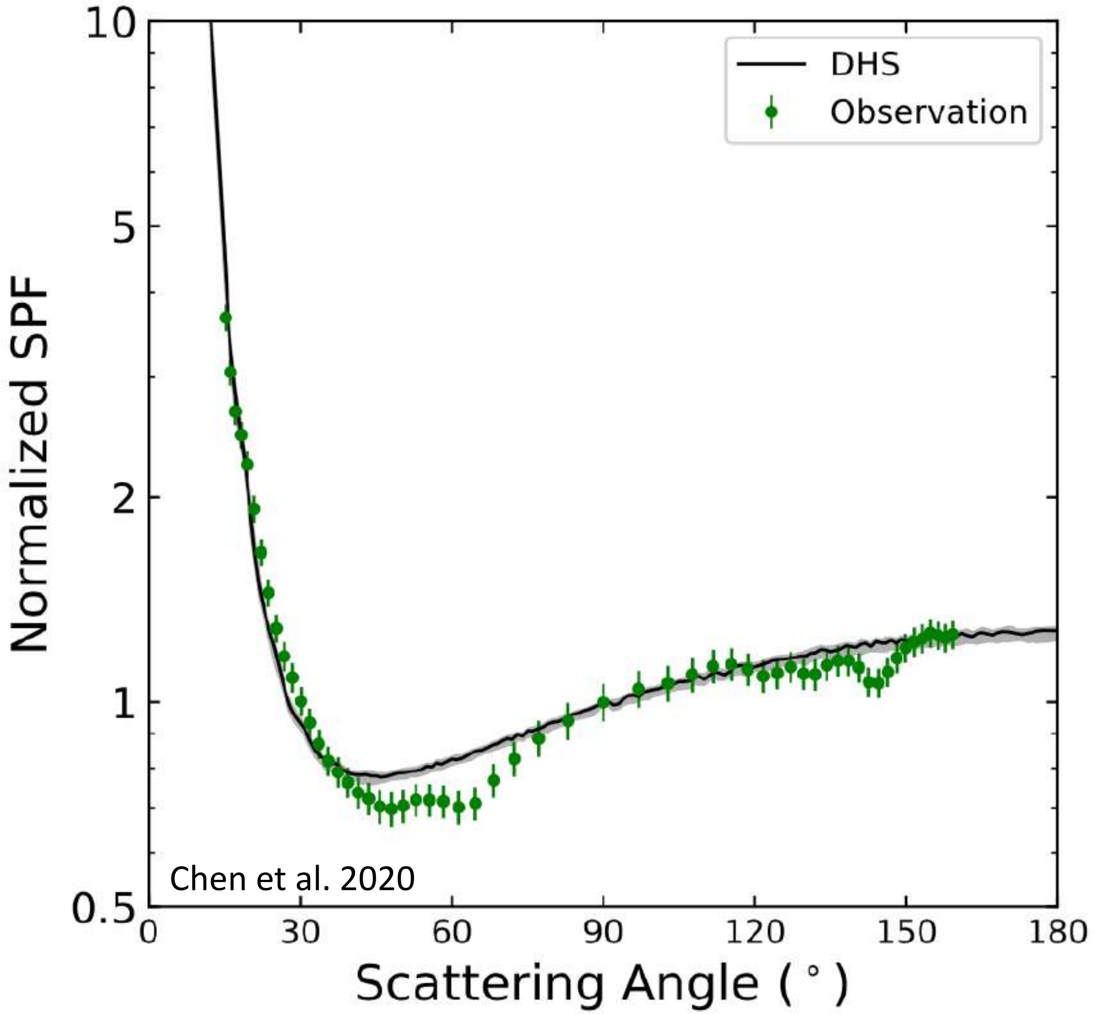




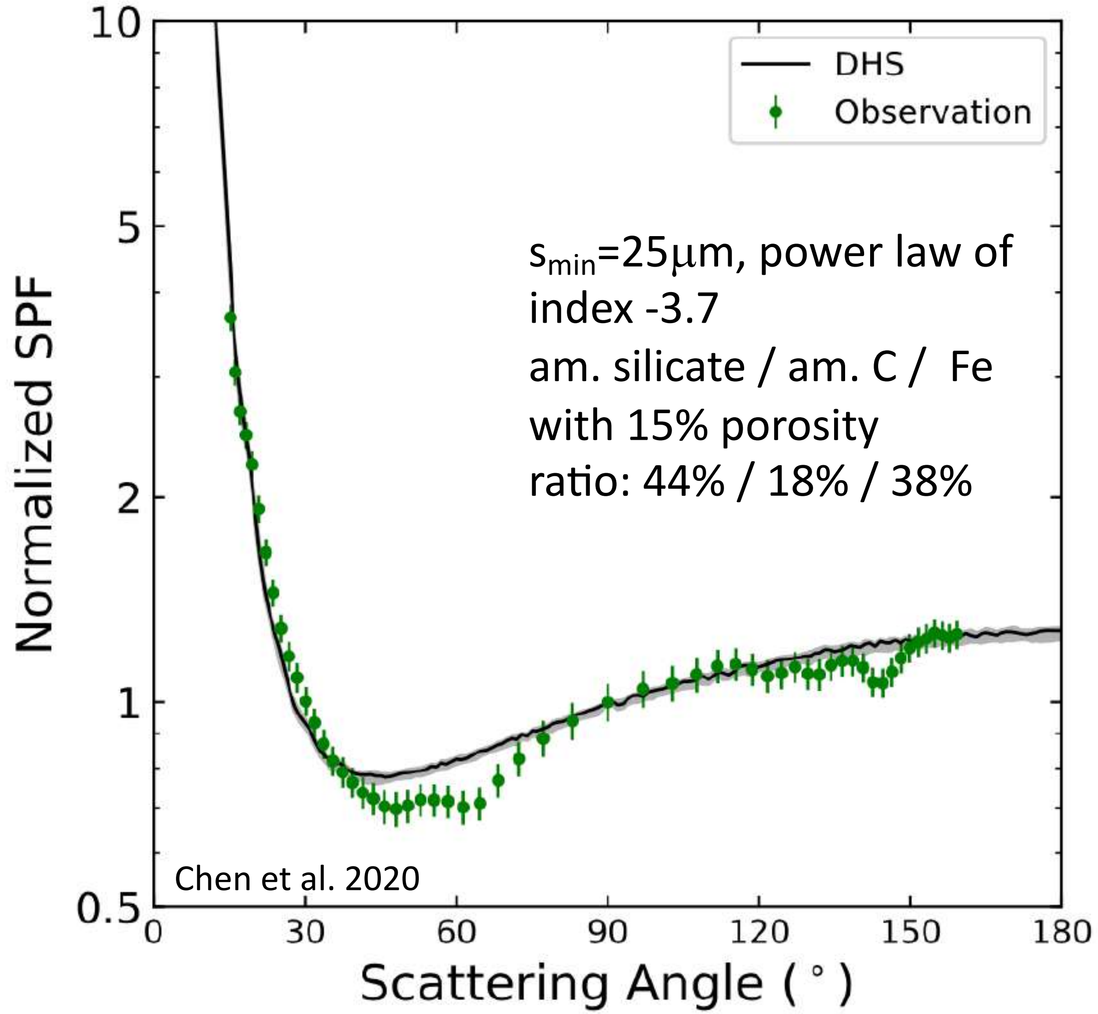


Peculiar scattering phase function (SPF) and polarization fraction

Interpreting the scattering phase function



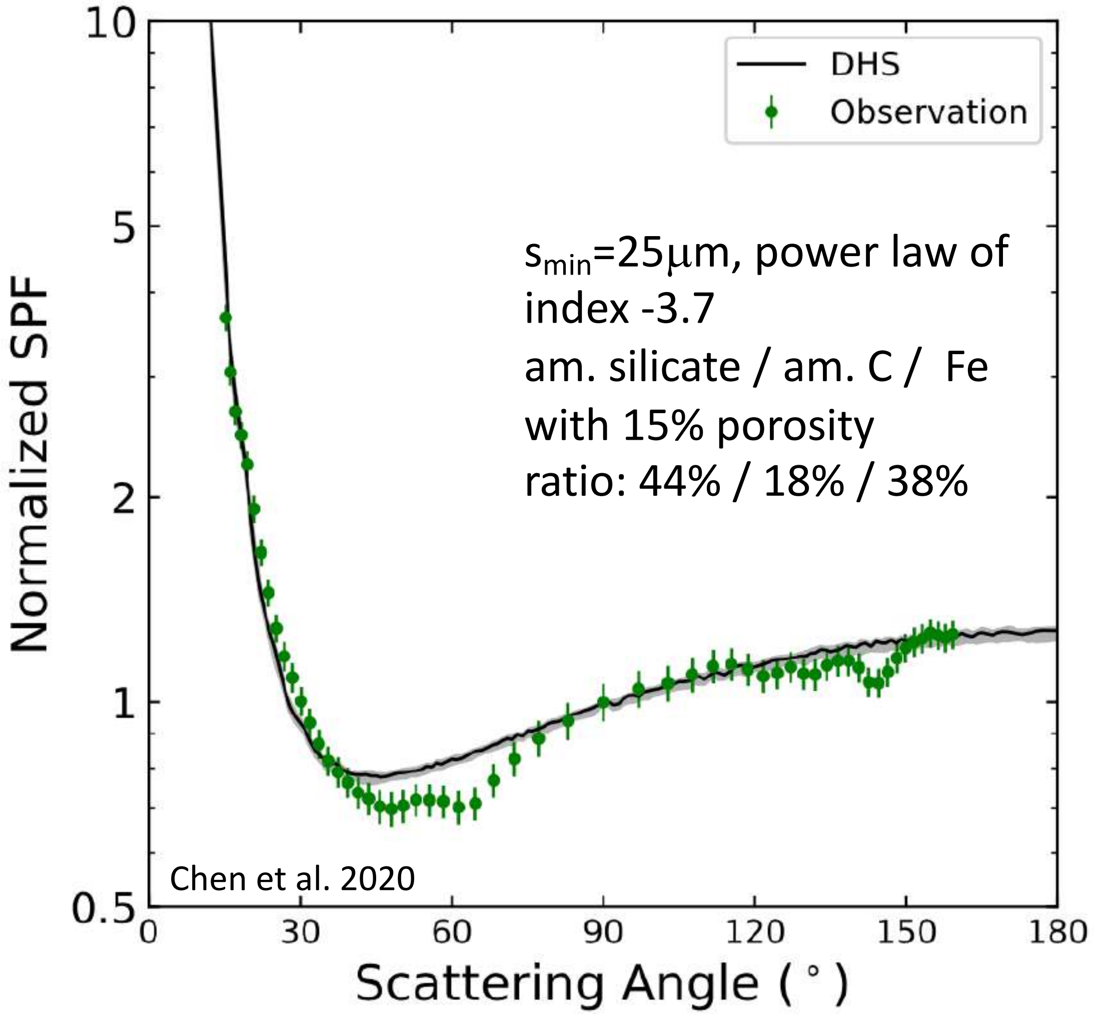
Interpreting the scattering phase function



s_{min}=25μm, power law of index -3.7
am. silicate / am. C / Fe with 15% porosity
ratio: 44% / 18% / 38%

Good match requiring highly absorbing material like Fe, but the polarization fraction is not compatible

Scattering phase function: interpretation



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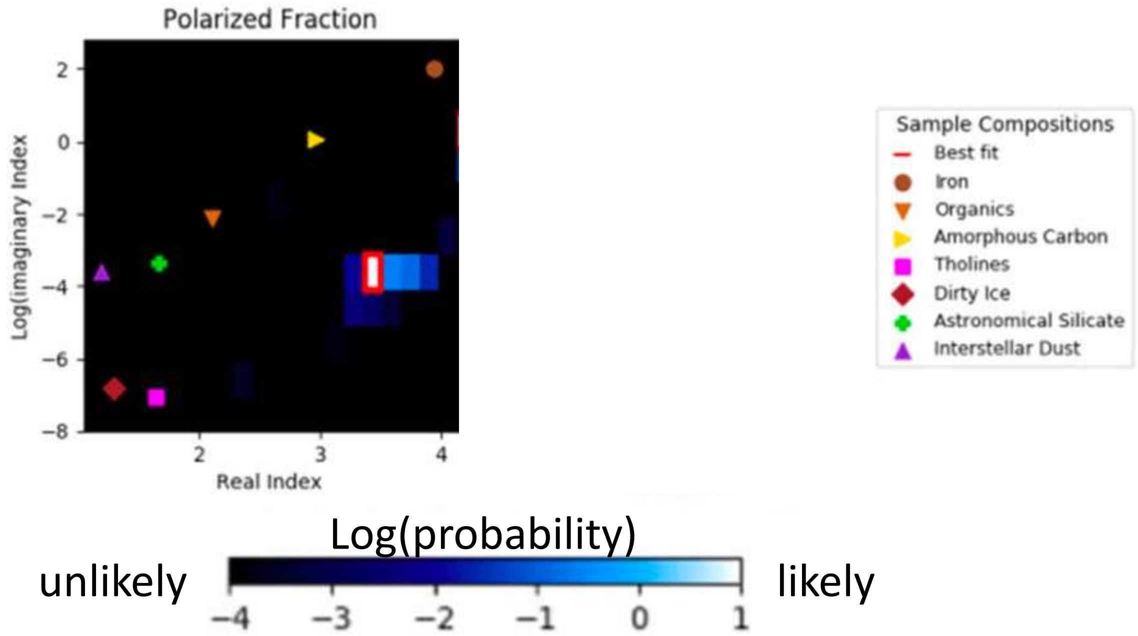
Chen et al. 2020

Probability map of the optical index (imag. vs real part)



Arriaga et al. 2020

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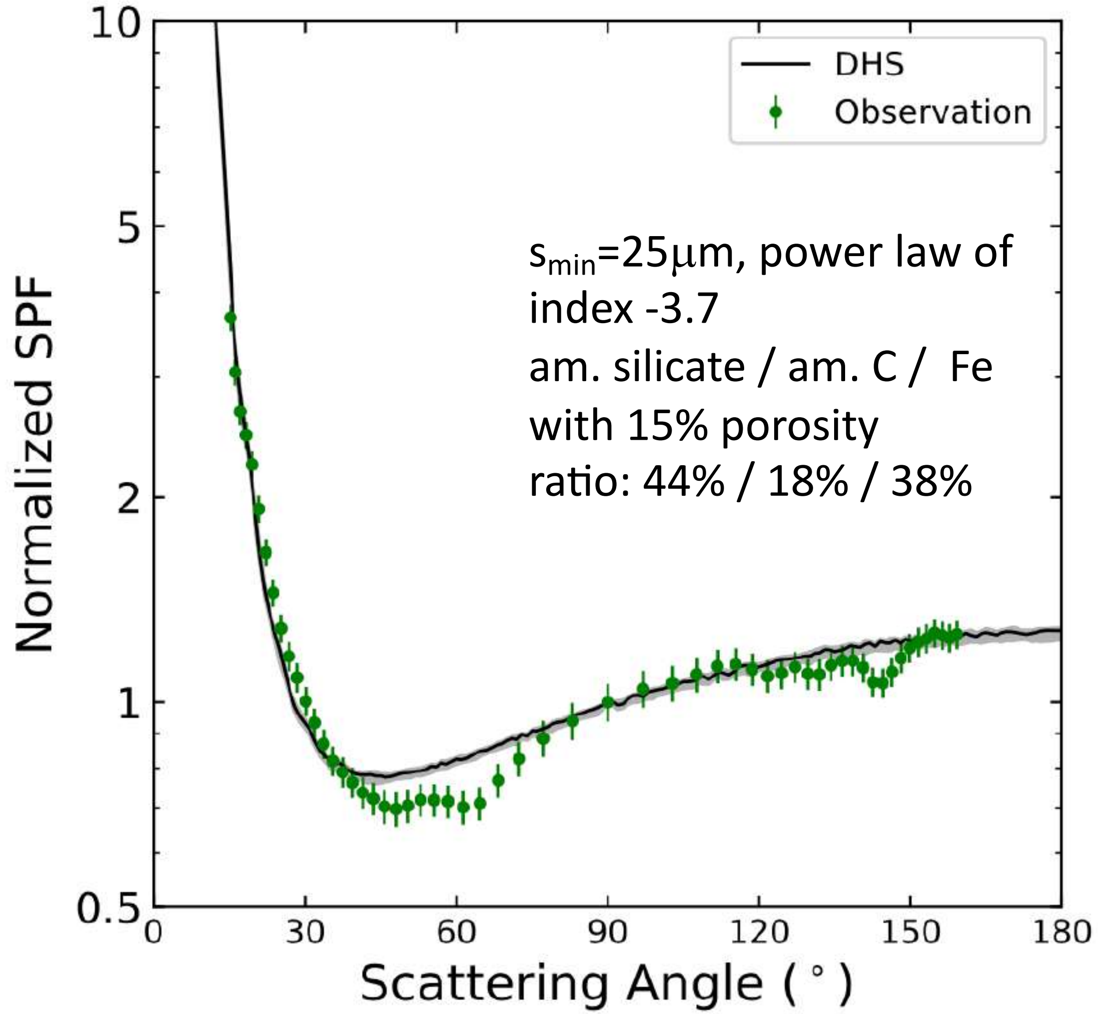

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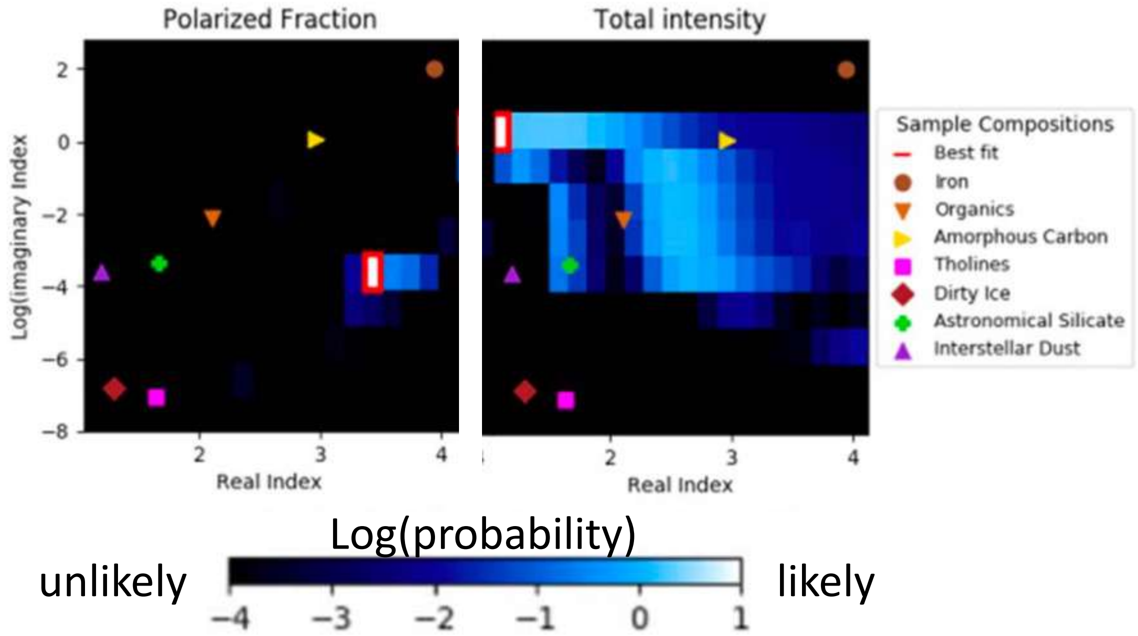


Arriaga et al. 2020

Good match requiring highly absorbing material like Fe, but the polarization fraction is not compatible

Change of strategy…

Numerical simulations

See next talk by Ryo Tazaki

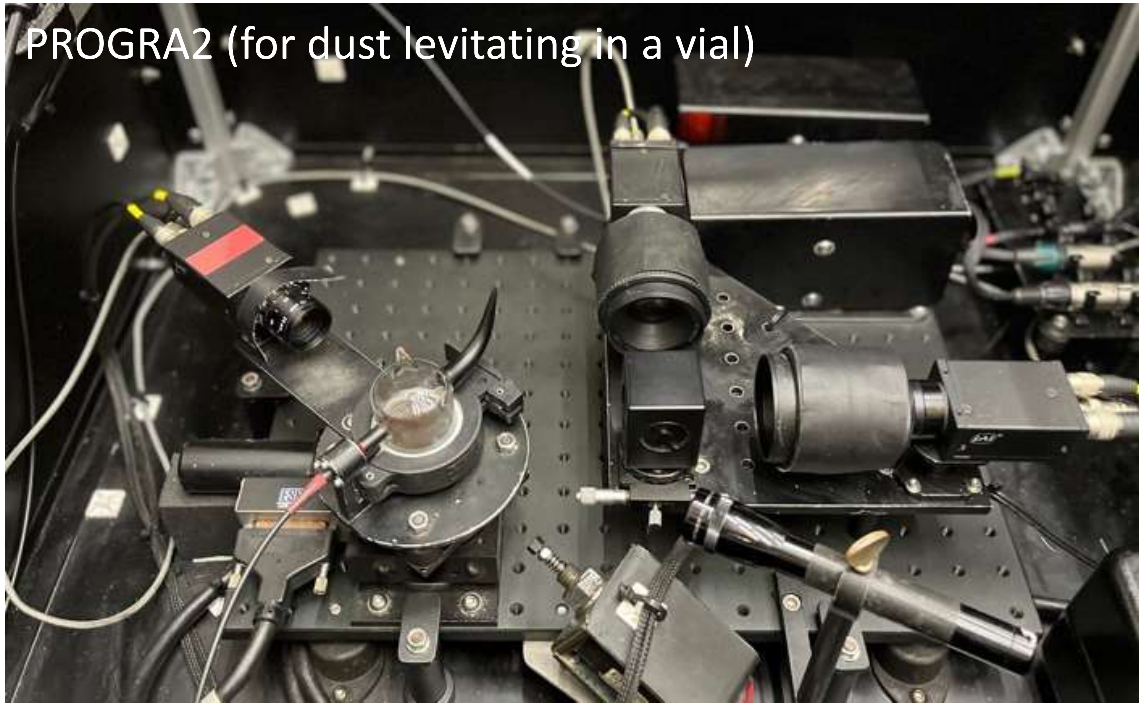
Lab measurements of dust analogues

Analogy with comets/asteroids

Levasseur-Regourd et al. 2020

Microwave experiments

Tobon-Valencia et al. 2022, cf also previous talk

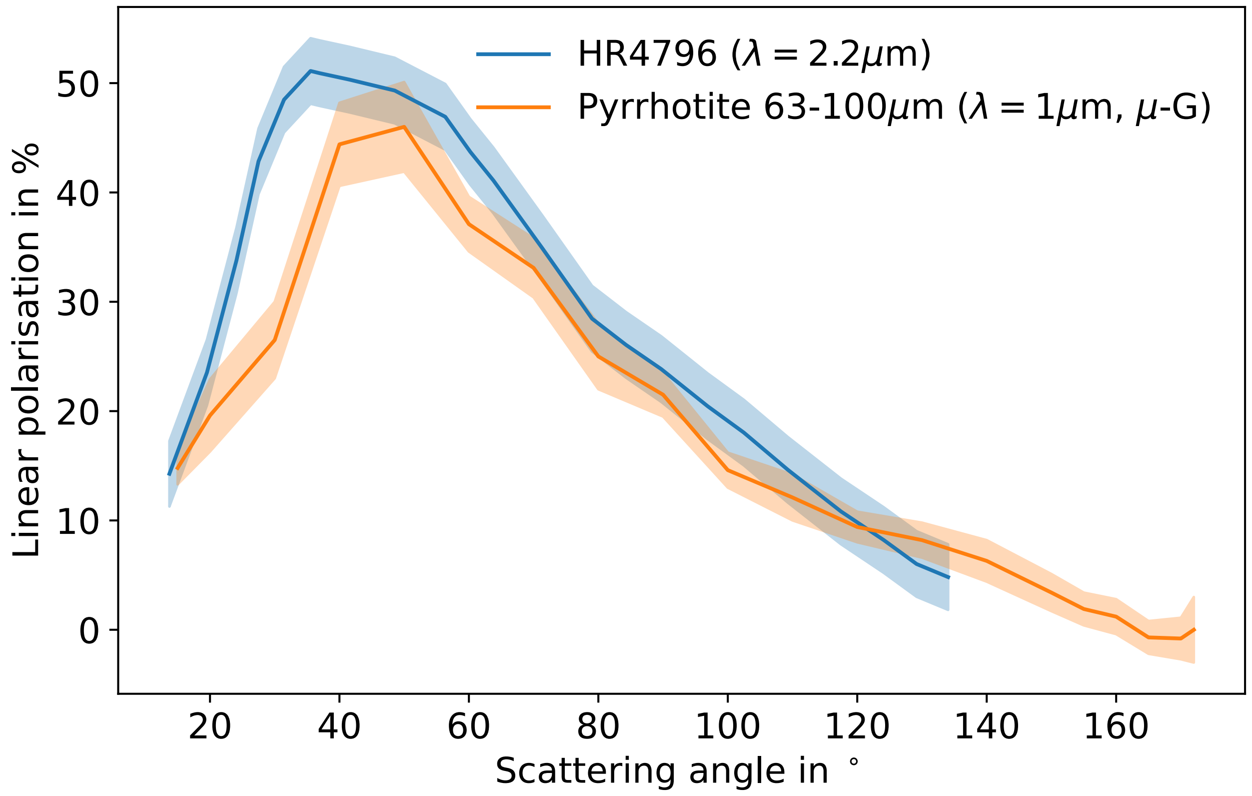


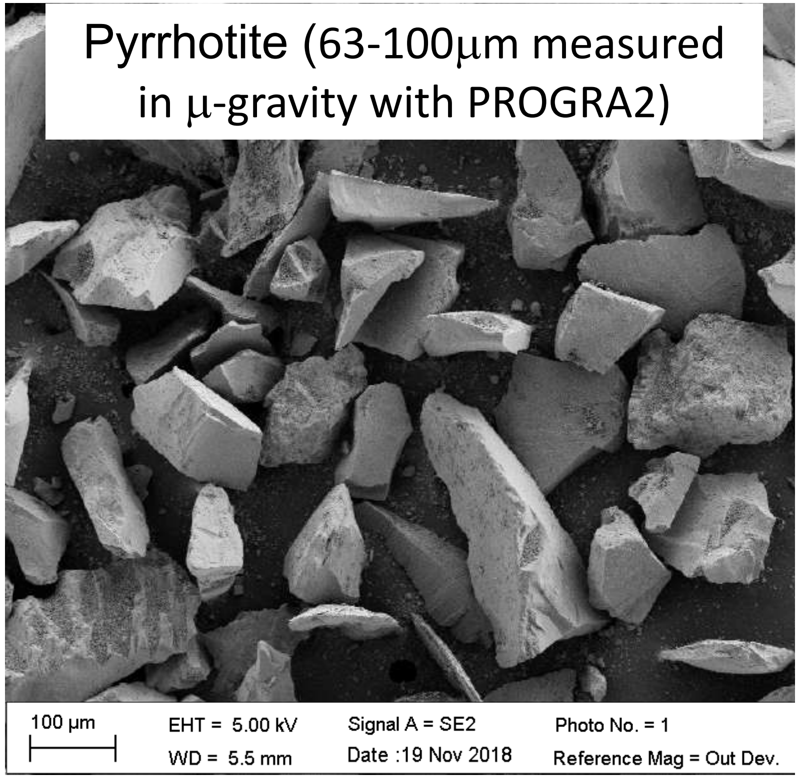
Worms et al. 2000
Hadamcik et al. 2023

Potin et al. 2018
Sultana et al. 2023

Iron sulphides in the dust of HR4796 ?

Comparison of the HR4796 NIR data with a pyrrhotite sample ($Fe_{1-x}S$ with $0 < x < 0.12$)

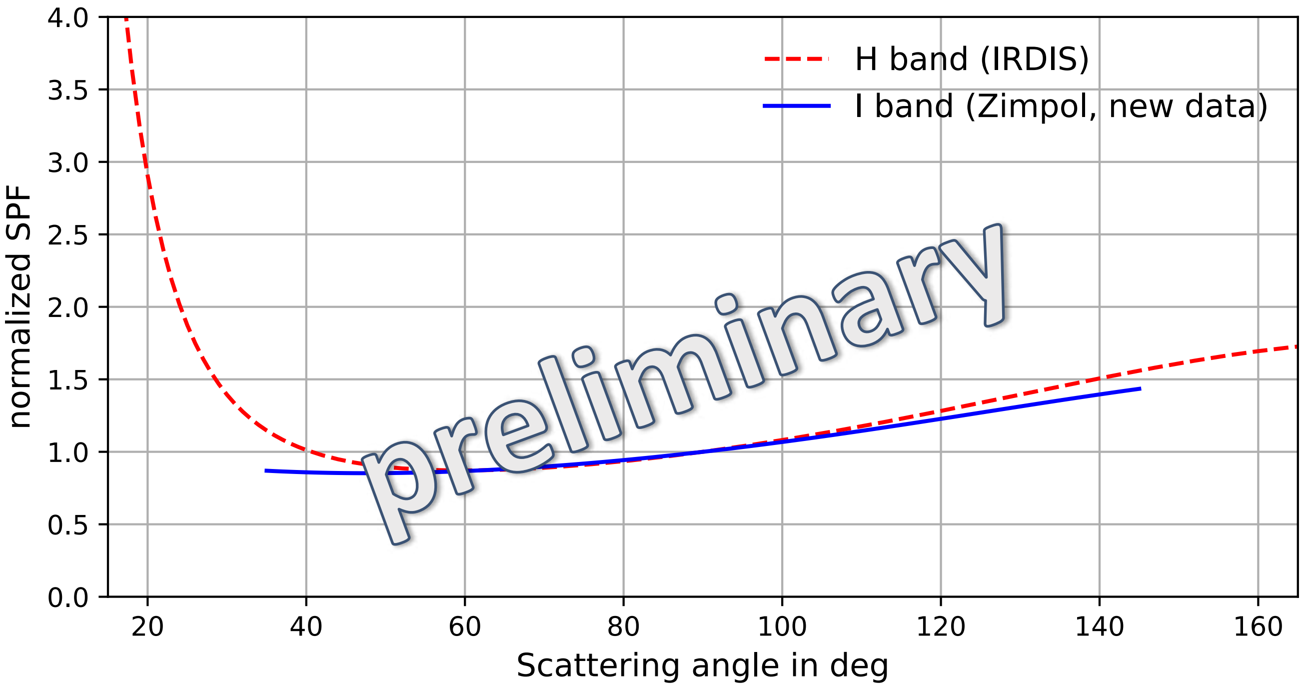


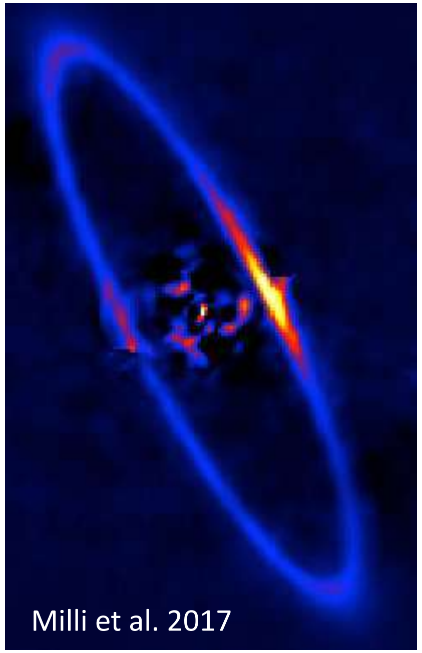


Good analogue but what about the scattering phase function in total intensity ?

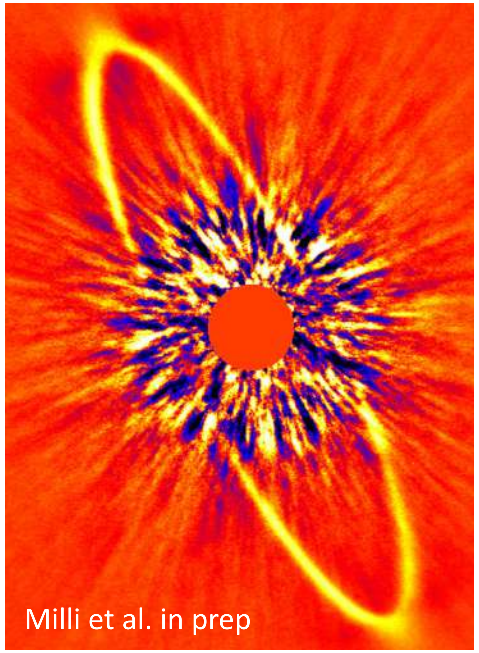
Total intensity data

No total intensity measurements with PROGRA2 in NIR on levitating samples, only optical data available → observations done with SPHERE/ZIMPOL in the optical (I band at 790nm)





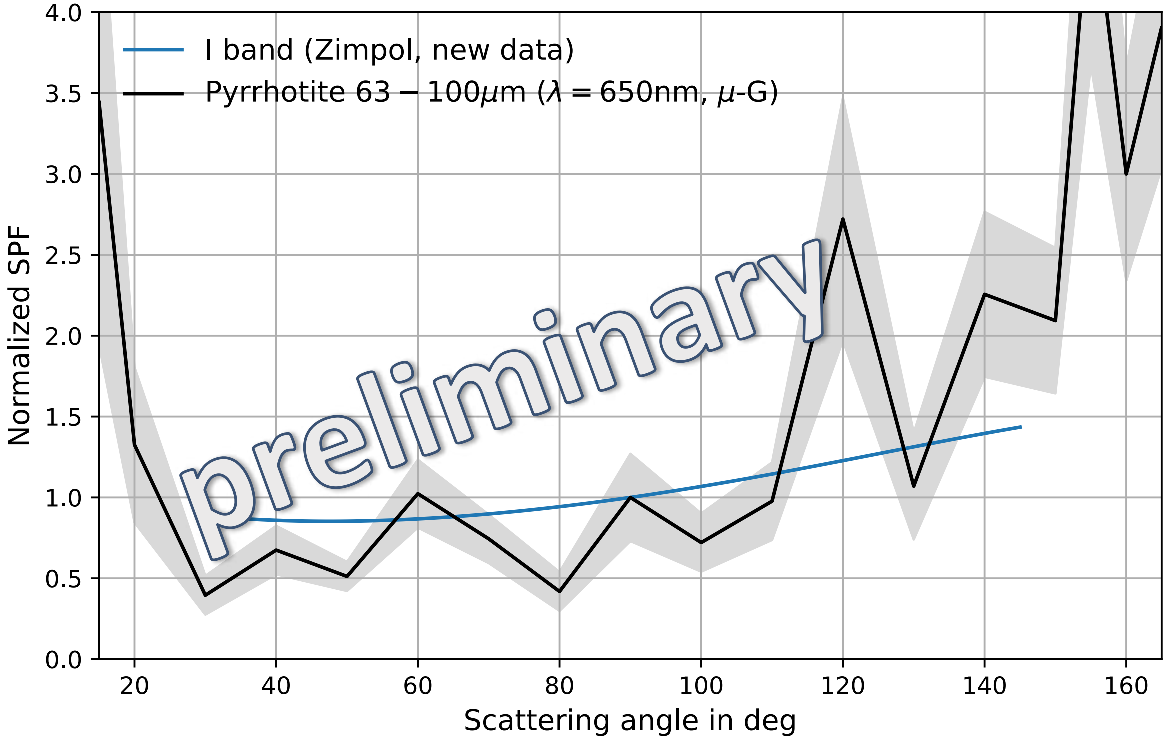
SPHERE H band



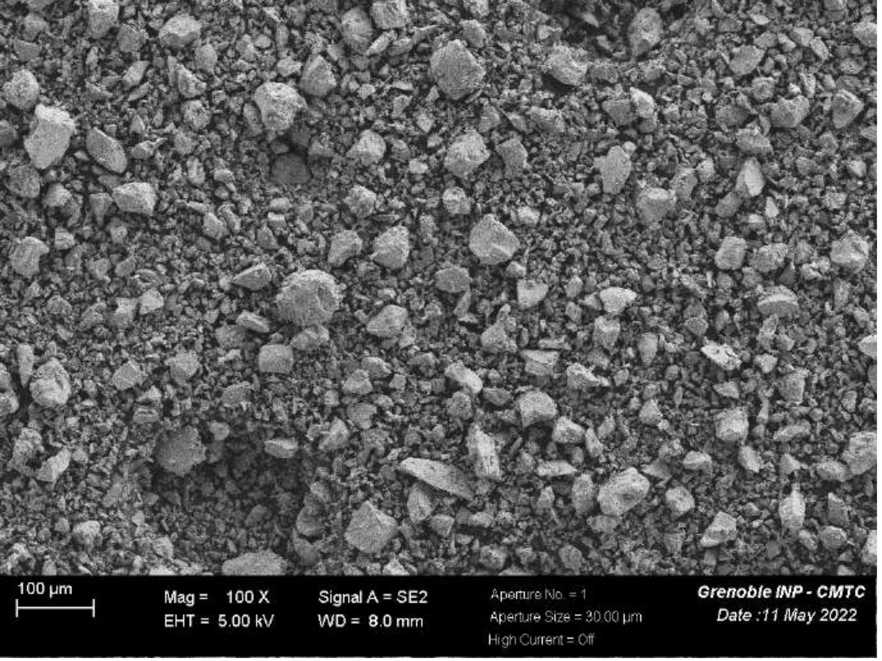
SPHERE I band

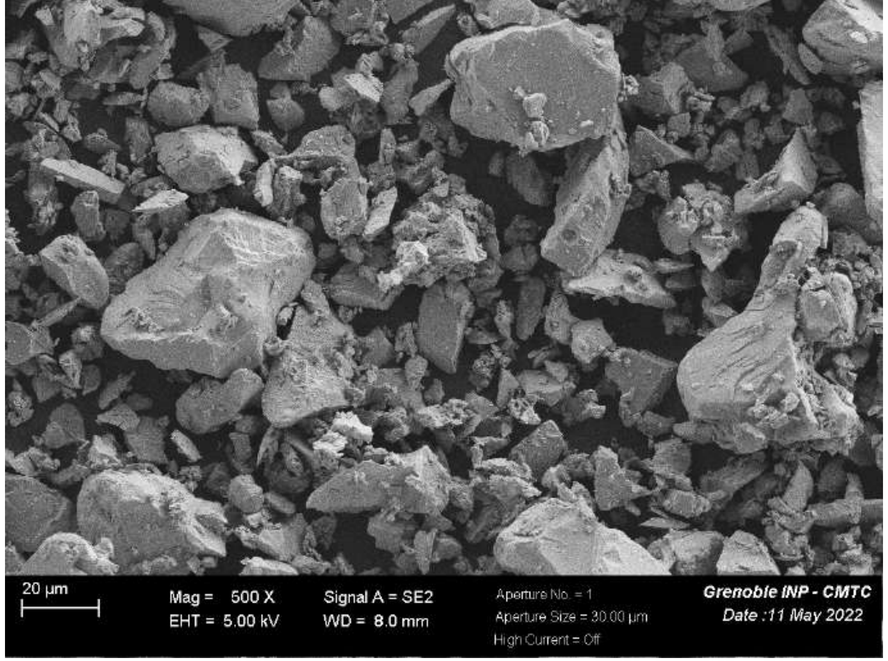
Mostly backward scattering, but harder to access the innermost regions in the optical

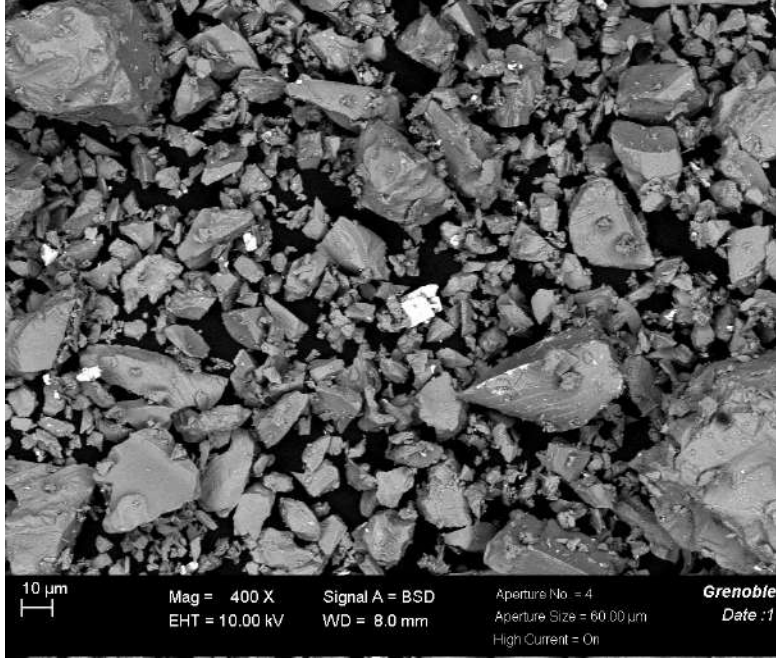
Comparing to optical data



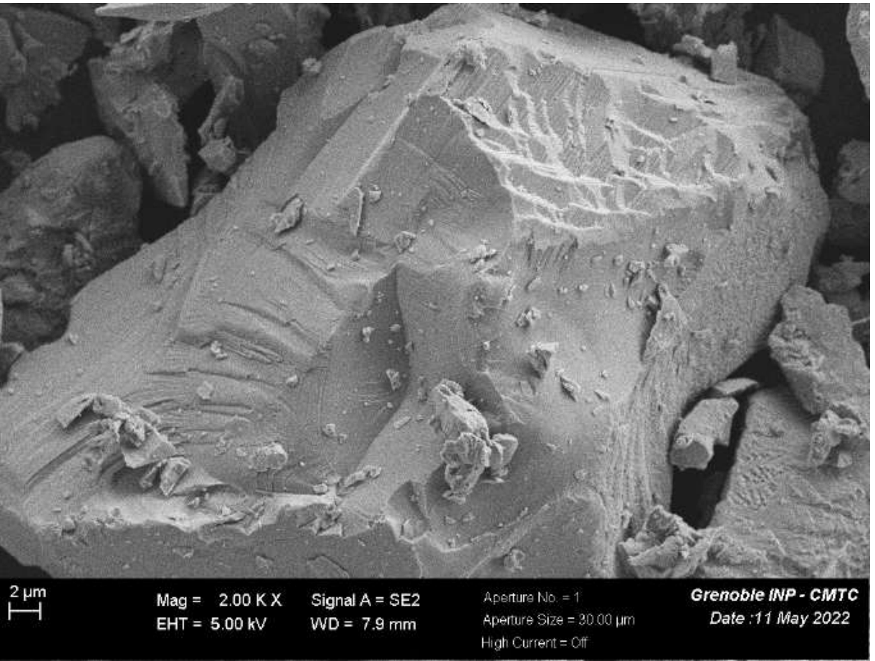
Relative good match despite large uncertainties

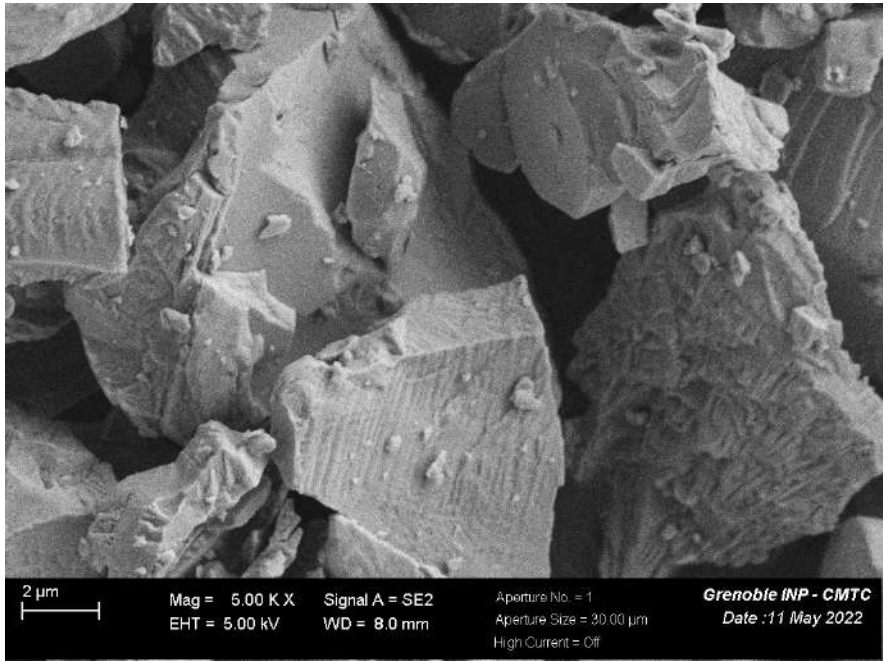


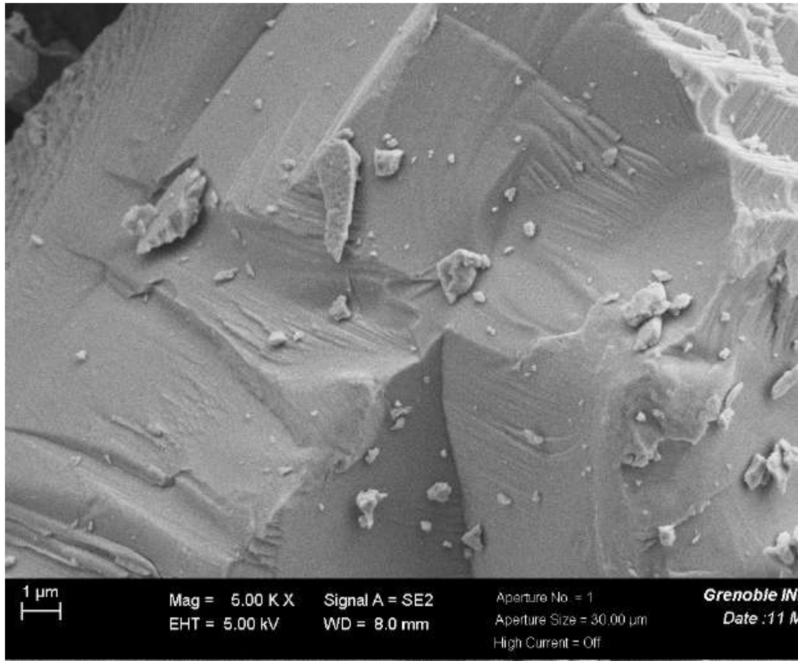




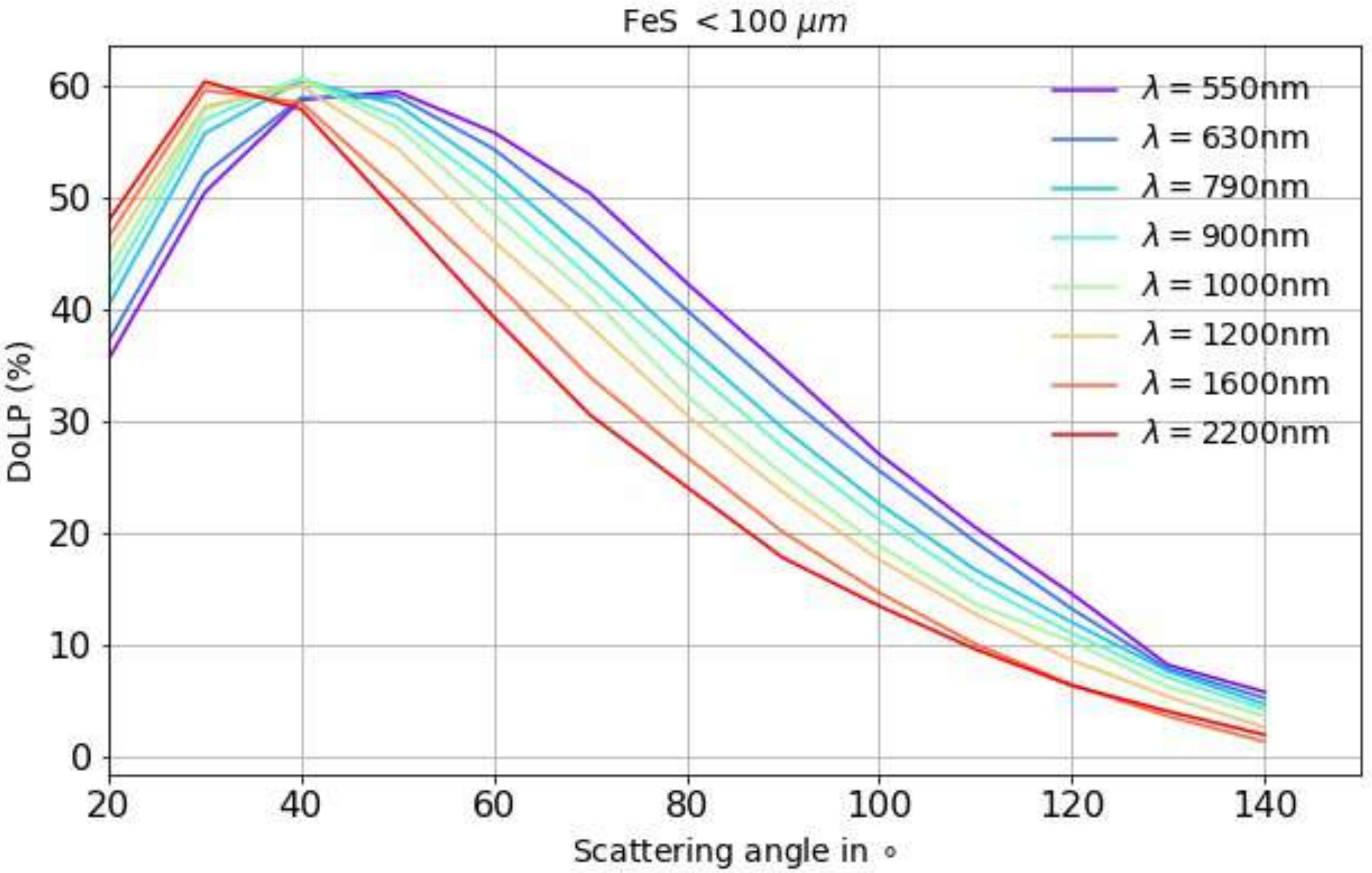
Iron sulfide FeS (mix of troilite and pyrrhotite)







Measurements done with SHADOWS for 1-100μm FeS dust deposited on a surface



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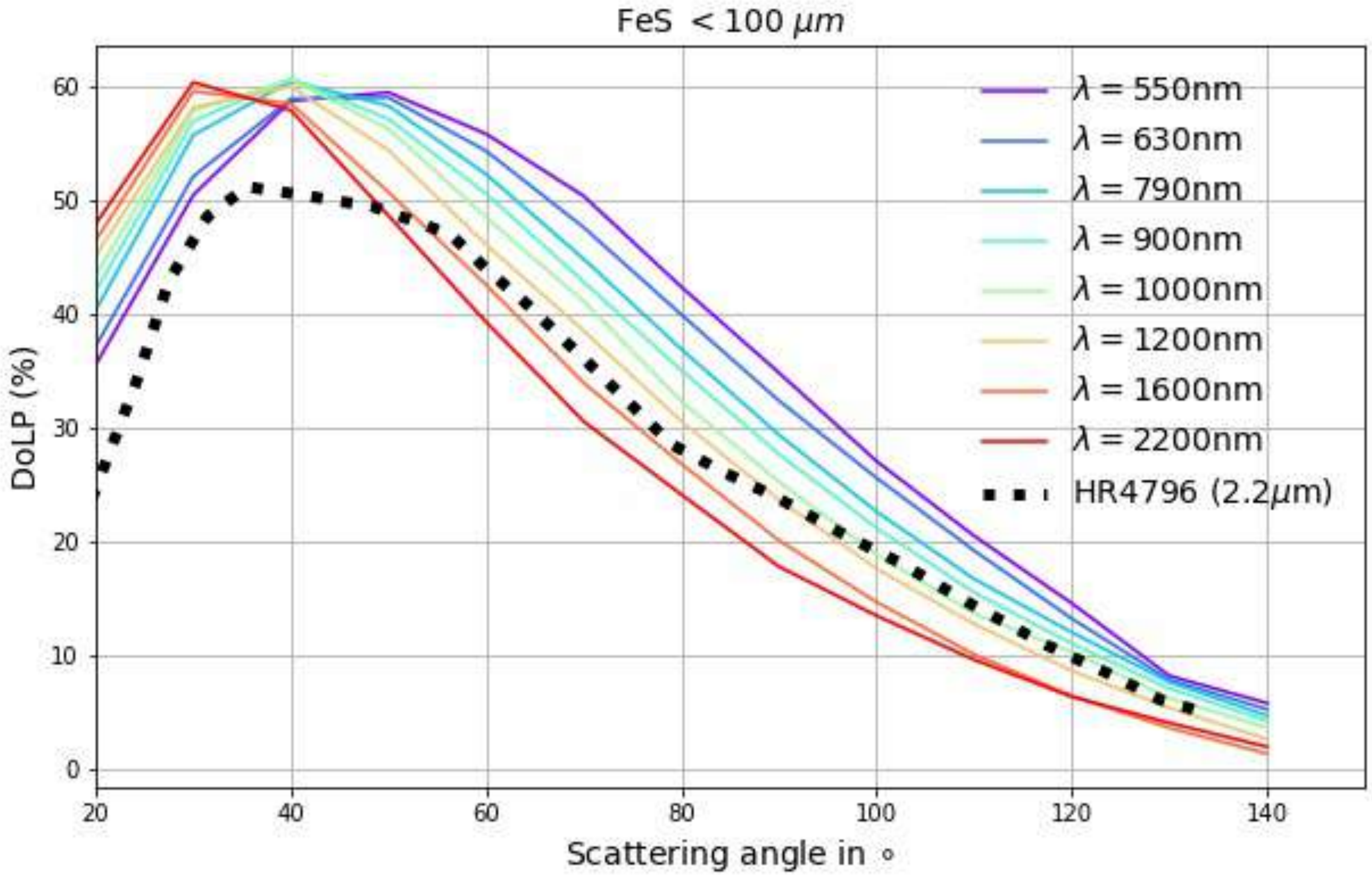
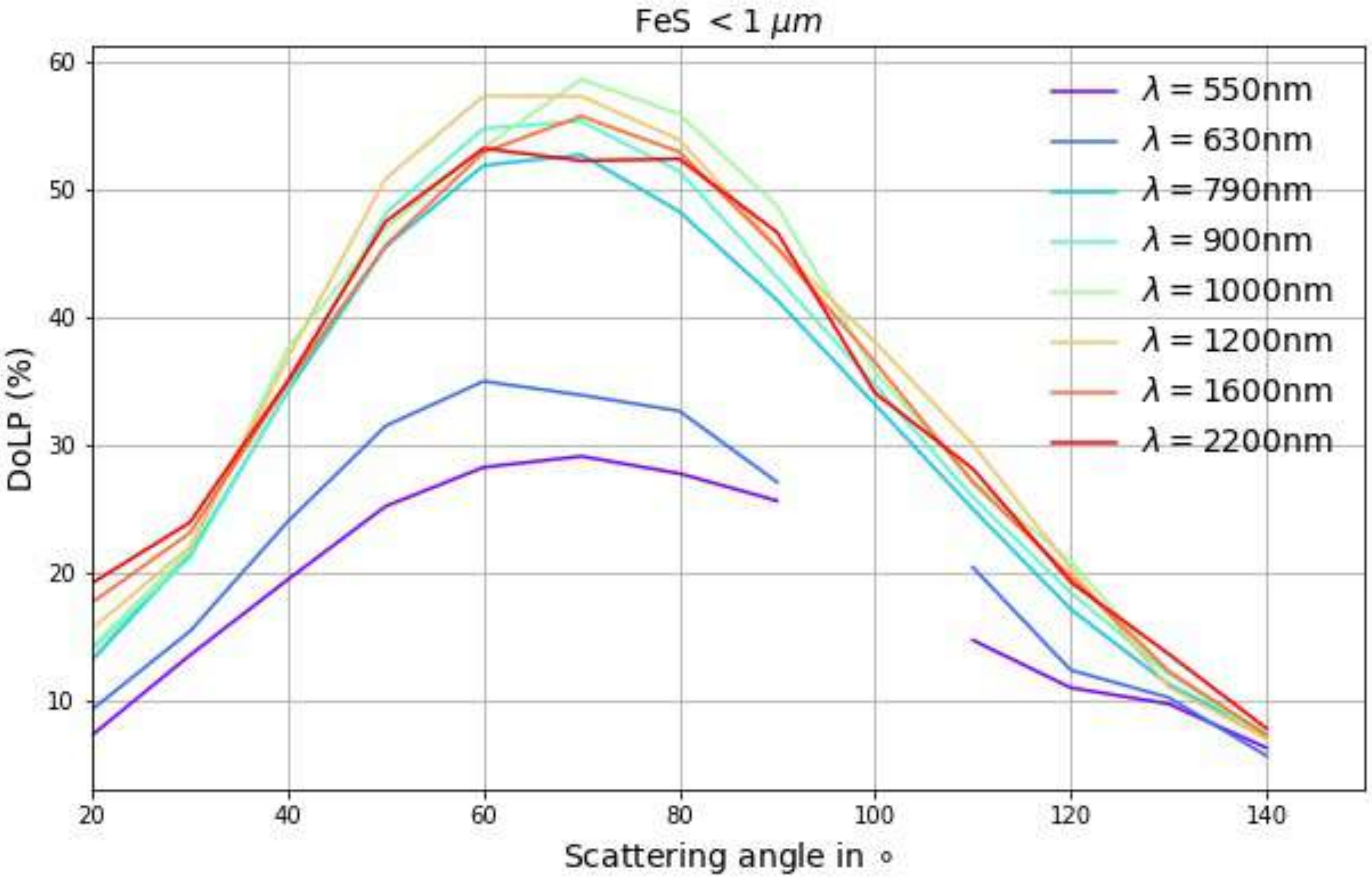


Measurements done with SHADOWS for sub-micron FeS dust deposited on a surface



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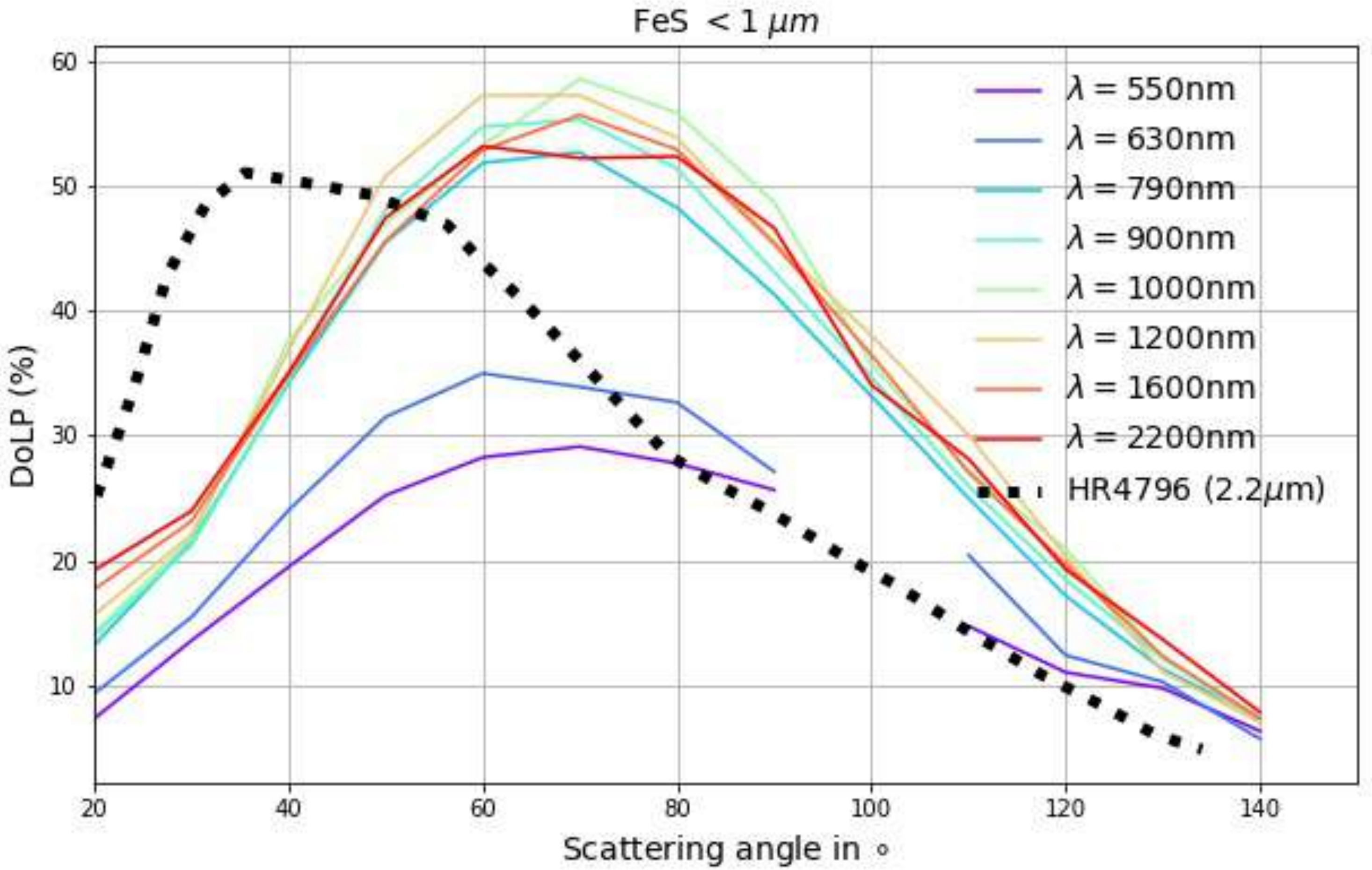
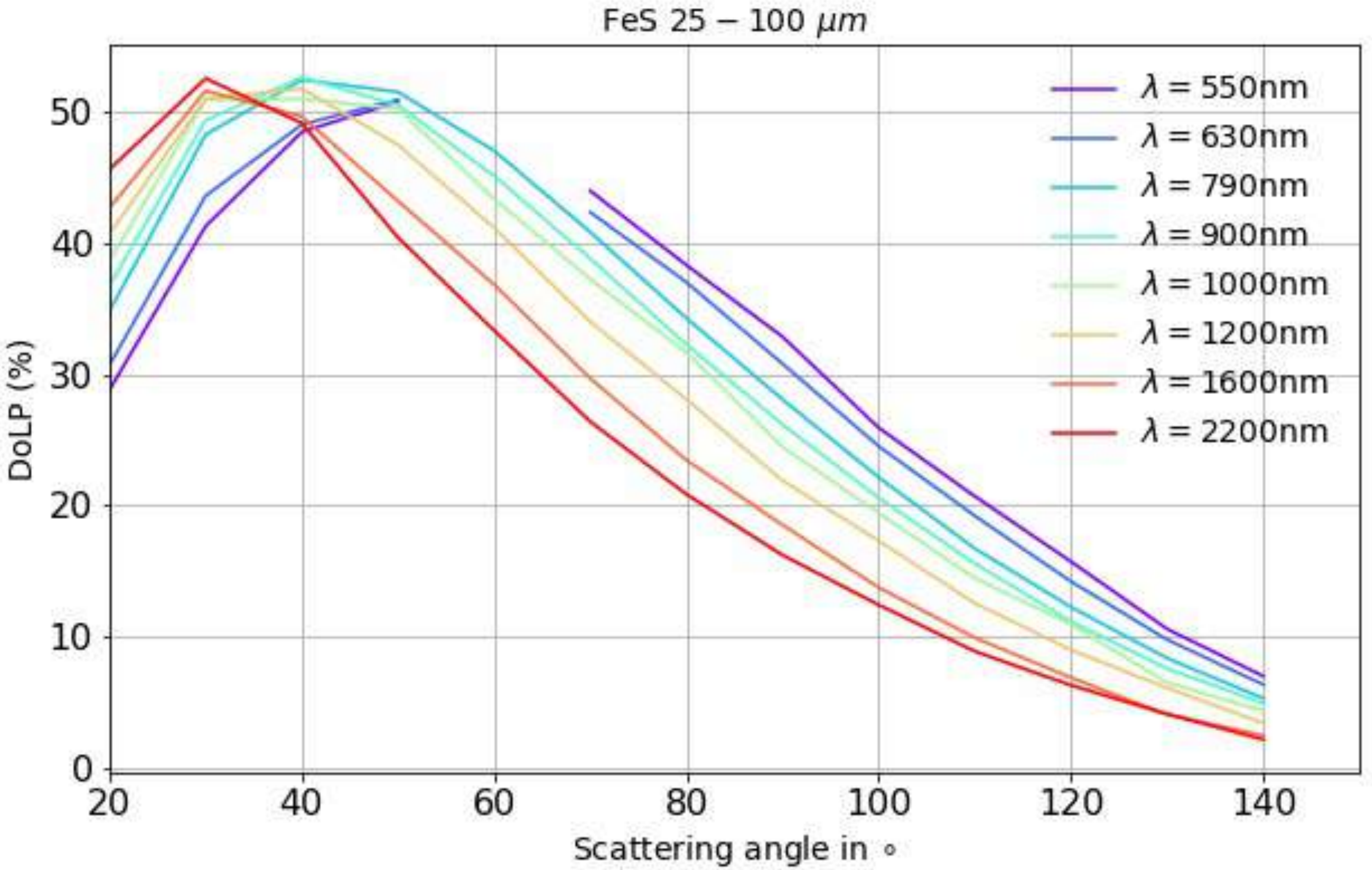


Measurements done with SHADOWS for 25-100μm FeS dust deposited on a surface



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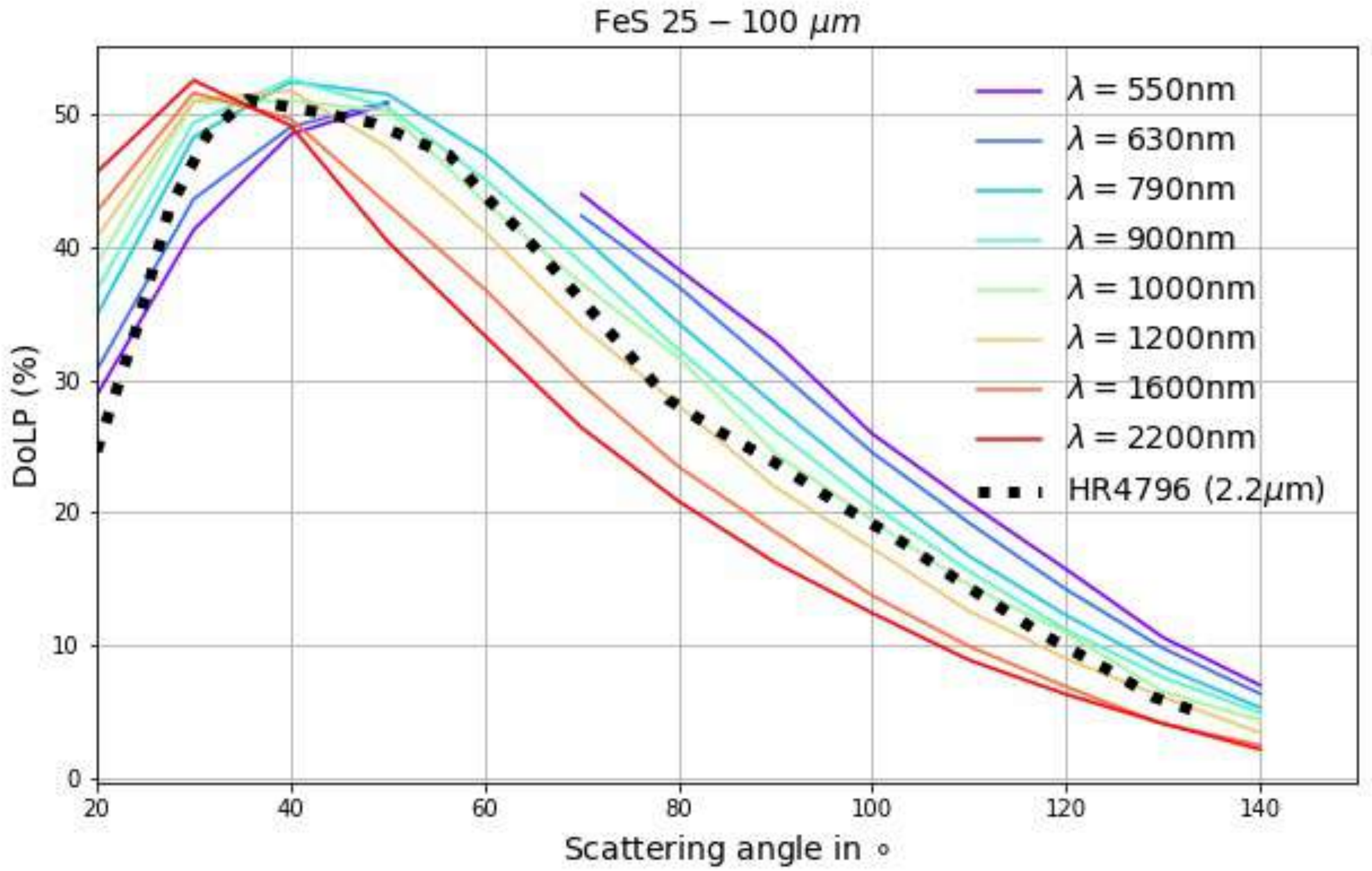
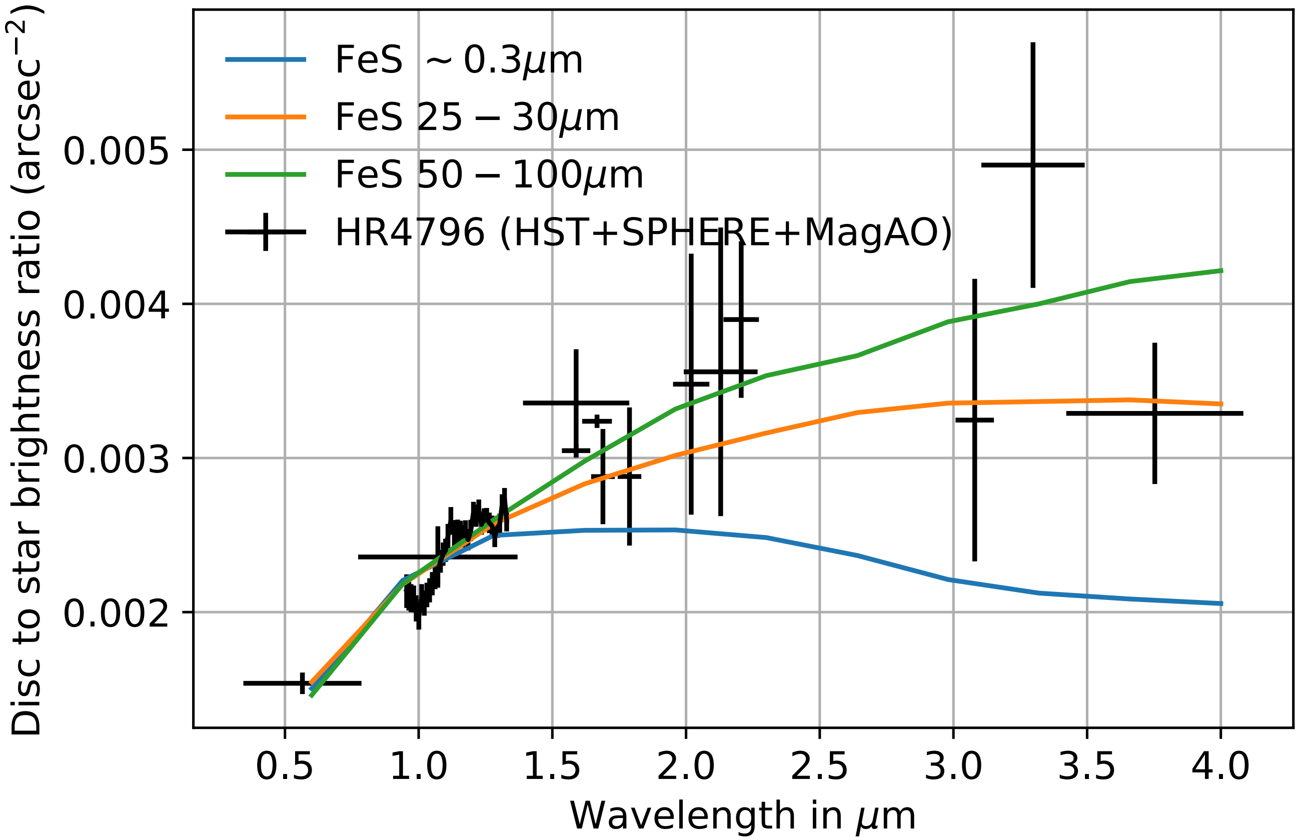


Last piece of evidence: reflectance spectrum



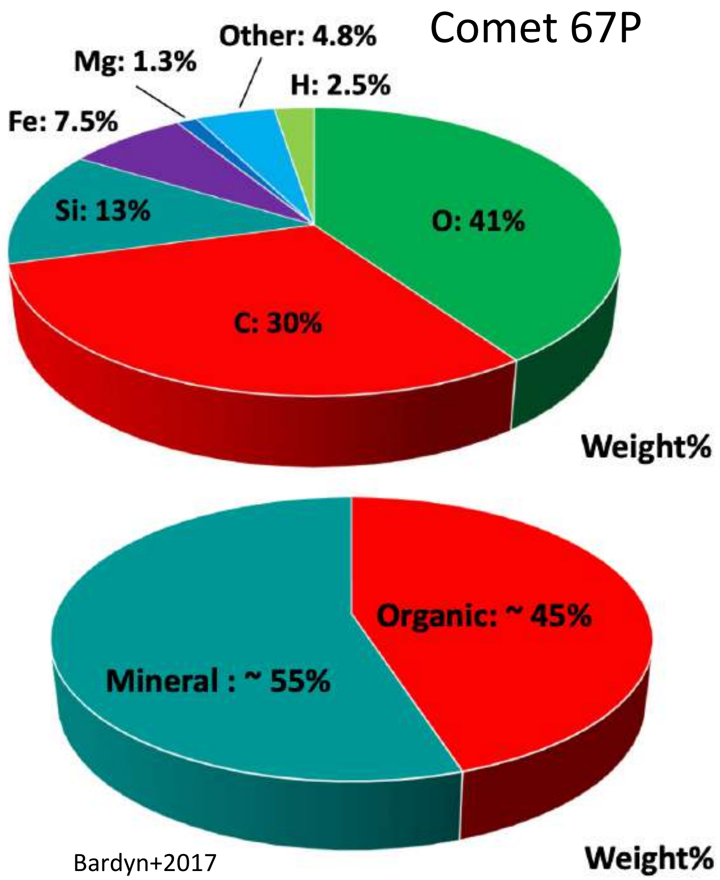
FeS reflectance spectra measured with SHADOWS (Sultana et al. 2023)
HR4796 spectrum from Rodigas et al. 2014, Milli et al. 2017

Why iron sulfides ?
The asteroid / comet connexion

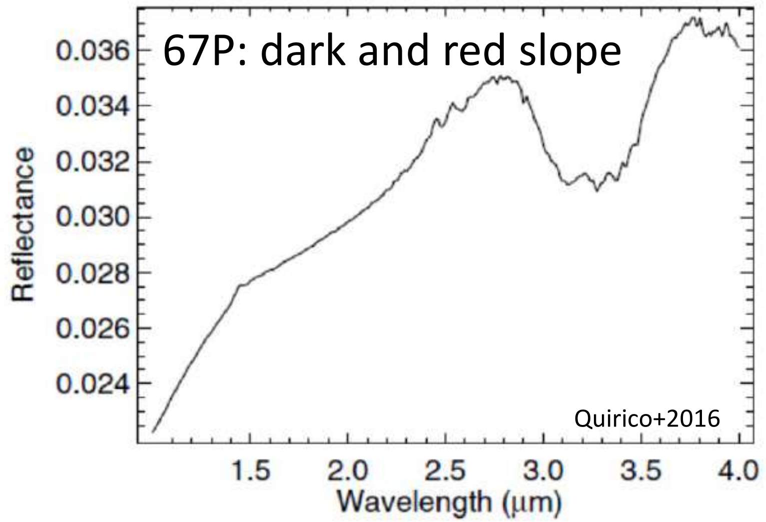
- Stratospheric IDP, Antarctica Micro-Meteorites, Wild 2 samples (STARDUST) all contain sulfides in the form of troilite FeS.
- Fe also present in comet 67P (COSIMA, Bardyn+2017)
- Opaque minerals (such as iron sulfides, Fe-Ni alloys) are responsible for the dark reflectance (from VIS to IR wavelengths) of cometary and primitive asteroids surfaces (Quirico et al. 2016).

> If opaque minerals such as FeS dominate the reflectance properties of these objects, they may also dominate their polarimetric properties.

- In cosmochemistry, long-standing problem of S depletion in the gas phase of protoplanetary disks: sulfide minerals such as FeS are likely the main carriers of S (Kama et al. 2019)



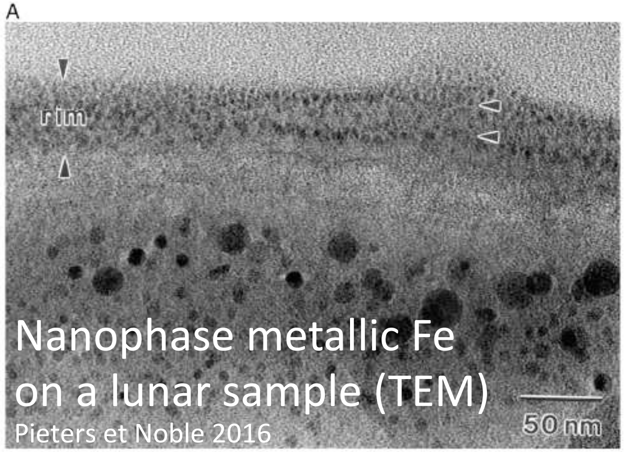
Bardyn+2017



Quirico+2016

Conclusions

- the presence of FeS is compatible with the scattered light properties of the HR4796 dust particles
  - Polarisation fraction
  - Scattering phase function
  - Reflectance spectrum
- Next steps: investigation with SHADOWS of the scattering properties of
  - mixtures of FeS and olivine (some measurements already done)
  - nanophase iron produced by space-weathering (on-going internship by Maelys Rigouleau)



Nanophase metallic Fe on a lunar sample (TEM)
Pieters et Noble 2016